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IS FIELD EXPERIMENTATION A RELEVANT METHOD TO STUDY THE EFFECTS OF CHANGES IN CHEMICAL CLIMATE ON FOREST ECOSYSTEMS?

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Abstract

Some results are reported from long-term field experiments with repeated additions of nitrogen fertilizers, acid, or lime. While large additions of chemicals to forest ecosystems may have effects qualitatively or quantitatively different from those of deposition with precipitation and dry fall-out, much of the objections towards the experimental design may be overcome by giving low but frequent applications of compounds normally occurring in the ecosystem (such as ammonium nitrate) or by studying primarily the aftereffects of substances more alien to the environment (such as elementary sulphur and sulphuric acid with pH <3). The range of acid/base conditions can also be widened by studying lime additions. When liming experiments have been running parallel to acidification experiments, we can expect reactions in opposite direction in both soil characteristics and tree growth. If this holds true, the existence of old liming experiments may help to predict long-term effects of acidification.

INTRODUCTION

The time factor is the greatest obstacle in experimental research in forest ecosystems. This applies in particular to research on the effects of the changes in chemical climate due to anthropogenic emissions within industrialized regions. The reasons are of different nature:

1. A slow change, such as increased deposition of acid or nitrogenous compounds has a low signal to noise ratio and therefore takes a long time to be discovered.
2. Application of large amounts of a chemical compound may cause "artefacts", different from those caused by slow deposition. This is true both when the compound is applied in more concentrated form than by "normal" deposition and when the concentration is "realistic" but the vector used abnormal (e.g. huge amounts of water).

3. Forest ecosystems may show a high resilience in certain respects, i.e. they can "buffer" a change in soil chemical and biological properties, as long as the tree stand is intact. When the stand is cut, which in most European forest is done at an age between 40 and 100 years, the soil biological system changes completely, and effects accumulated over the rotation time may appear. When the nutrient cycling is interrupted by clear-felling, excessive nitrification may occur, followed by leaching of nitrate and cations, denitrification and acidification, all processes which imply potential environmental hazards. Acid precipitation may also have delayed effects in a similar way.

Our question is now: can we in experimentation find some method to speed up the small annual additions of nitrogen or other substances with biological effects to a forest ecosystem with a minimum of artefacts?

Nutrient optimization experiments

In Swedish agricultural research a major long-term research project was started in 1957, called soil fertility experiments, studying effects of different agricultural regimes on yield and soil (Jansson 1975). It so happens that a small forest project with a partly similar scope was started in the same year, the nitrogen optimization experiment E1 Hökaberg at Remningstorp in South Sweden. However, this experiment had to be concluded in 1970, as the plots were too small and attacks of barkbeetles affected some of the plots.

New experiments were started in 1967, 1969, 1971 and 1974 in four different sites, two young spruce plantations and two young pine stands in different parts of Sweden. The effects of nitrogen (in different dosages) and other nutrients have been studied on plots annually fertilized with nitrogen and with other nutrients added at 2-3 year intervals in factorial design. The nutrient additions used to maintain elevated nitrogen levels in the foliage are shown in Fig. 1 for some of the regimes in the spruce experiment E26A Stråsan. Irrigation, liming and acidification have been studied in separate experiments at most sites, at two levels of nutrients (with and without NPK).

Present results

Growth results from the experiments have been reported at intervals (Albrektson et al. 1977, Tamm 1980, Tamm & Wiklander 1980, Aronsson & Tamm 1982, Tamm & Aronsson (in press), Tamm 1982, Aronsson (in press).

Some of the results pertinent to the present subject are the following: Nitrogen availability has been a growth-limiting factor on all four sites; the response to moderately increased nitrogen levels has been dramatic, particularly in spruce (*Picea abies* Karst.). With increased nitrogen supply there is a response to phosphorus in spruce; in both spruce and pine (*Pinus sylvestris* L.) low levels of boron in the foliage occur at high nitrogen levels, with associated growth disturbances. Boron application was not tested separately in the Stråsan experiment, but half the plots received a fertilizer mixture containing potassium, magnesium and the micronutrients boron, manganese, copper, zinc and molybdenum. As seen in Figs. 2-3 there is an almost consistent superiority in tree growth on these plots, if they also got nitrogen. While conventional forest fertilization adds high amounts of fertilizer at intervals of several years, annual fertilization needs comparatively low dosages to maintain high foliage

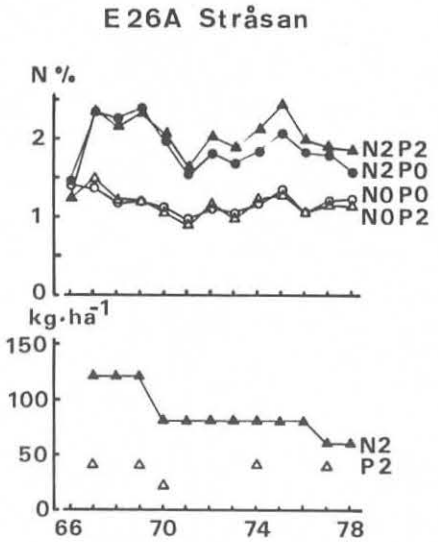

Fig. 1. Nitrogen levels in exposed current spruce needles at four fertilizer regimes at the Stråsan experiment, altitude 350 m, middle Sweden (upper diagram), and the amounts and times of fertilizer application (lower diagram). Experiment started in 1967.

levels of nitrogen, thus decreasing the risk for "artefacts" (e.g. salt effects on soil organisms). As illustrated in Fig. 1, nitrogen regime N2 amounts to 60 kg N per hectare and year from 1977 onwards. This seems to be enough to maintain the foliage nitrogen level (dormant season samples) reasonably constant, well above the control. Also nitrogen regime N1 keeps the foliage level consistently elevated at 30 kg N per hectare and year (not illustrated) and increases growth to about 2/3 of maximum (Fig. 2 and 3).

A similar risk for "artefacts" is apparent in experiments with acidification with sulphuric acid or sulphur powder (Tamm & Wiklander 1980). Even the careful Norwegian experiments (Tveite 1980) have used large amounts of groundwater (corresponding to the precipitation during very wet years) and clear effects were not obtained until the water was acidified to pH 2-3. In our experiments the acid treatments have been given for a limited number of years (3-8) and now the main emphasis is given to the aftereffects on both tree growth and soil organisms.

In the case of liming the addition has so far been made at the start only, as previous experience tells us that lime effects on soils extend over long periods (Fig. 4). Experiments with repeated very low dosages of lime do not seem to have been made in forest ecosystems and most agricultural liming experiments use applications of one to several metric tons per hectare.

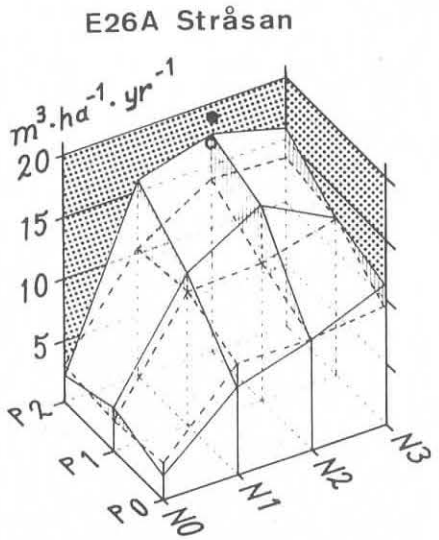

Fig. 2. Stem volume growth 1973-1978 at different nutrient regimes in the Stråsan experiment. Upper surface (solid lines) indicates growth with addition of a mixed fertilizer containing potassium, magnesium and the micronutrients B, Cu, Mn, Mo, and Zn. Lower surface indicates (broken lines) growth on plots not supplied with this mixture. Each treatment has been given on duplicate plots.

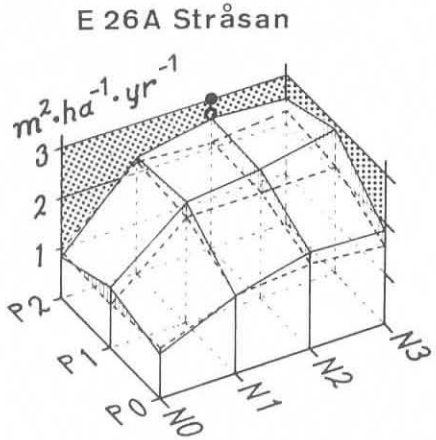

Fig. 3. Basal area growth 1979-1982 in the Stråsan experiments. Symbols as in Fig. 2.

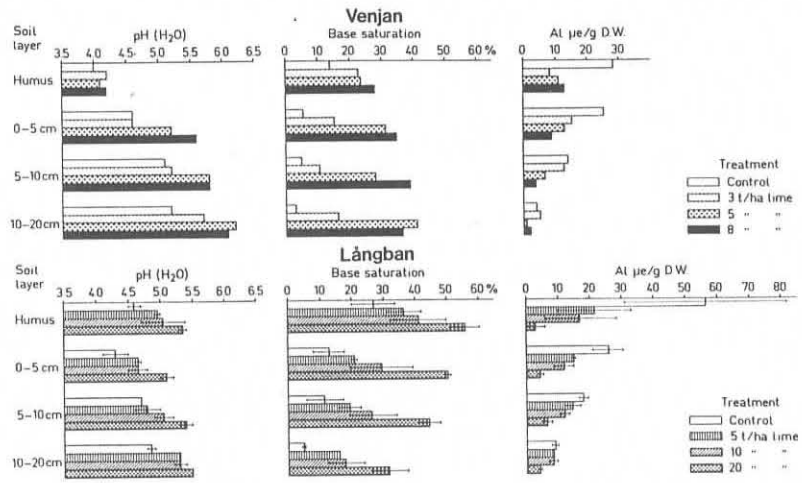

Fig. 4. Long-term effects on pH, base saturation and exchangeable aluminium in two old Swedish experiments, Venjan (1913), and Långban (1913). The Långban treatments were given to duplicate plots (plot differences indicated), while Venjan had no replicate. Soil sampling in 1982.

The final results from the optimum nutrition experiments and from the acidification experiments are of course not yet evident. It may however, be of some interest that soil nitrification capacity has increased considerably in the experiment E55 Norrliden after fertilization with urea (Popovič 1977). The same has happened in Experiment E63 Åseda after urea fertilization at relatively low rate. In both cases acidification had decreased pH and base saturation, and it depressed the nitrification occurring at Åseda. The acidification was made with sulphuric acid at Norrliden, with elementary sulphur at Åseda. At first a positive growth effect of acid application 1971-1976 was established on non-fertilized plots at Norrliden (significant at the 5 per cent level when growth was measured as basal area growth 1972-79, Tamm & Wiklander 1980). On NPK-fertilized plots the effect was negative (significant at the one per cent level, calculated in the same way). With basal area growth for the three year period 1980-1982 no significant relations were obtained and there was no tendency at all to positive effects of the acid (Fig. 5). While this may be due to the short measuring period, it is also possible that the unexpected growth increase after acid application was temporary only and that the unfavourable soil changes are now starting to affect tree growth (cf. Tveite 1980).

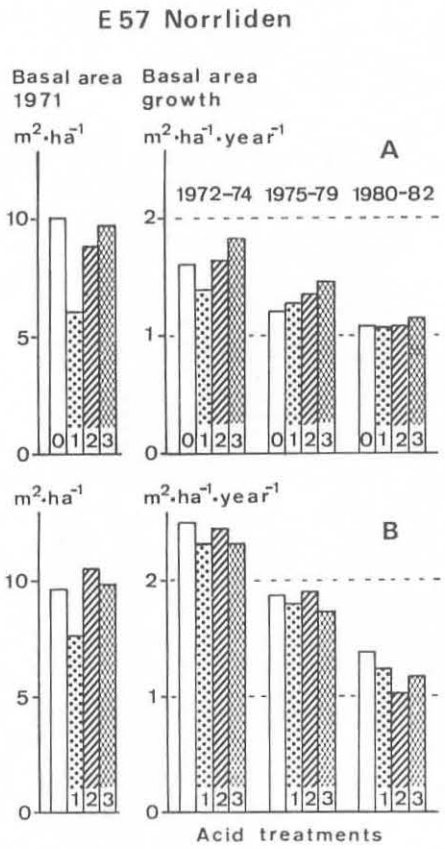

Fig. 5. Basal area 1971 and basal area growth in the experiment E57 Norrliden. The plots in the upper diagram (A) received dilute sulphuric acid only 1971-1976 in amounts from 300 kg H_2SO_4 (1) to 900 kg (3). The plots in the lower diagram (B) received NPK fertilizer in addition (ammonium nitrate supplied annually). Means of three replicates.

Effects of clear-felling

The present optimum nutrition experiments cannot yet answer the question asked in the introduction: will something dramatic happen in a forest ecosystem "saturated" with nitrogen, if the stand is cut. However, the small nitrogen optimization experiment E1 Hökaberg was cut in 1970 after nitrogen fertilization (nitrochalk) in amounts varying from 625 to 3 900 kg nitrogen per hectare (divided in annual applications over a 13 year period, 1957-1969). While the stand had responded positively to nitrogen during the first years, and to NPK for a somewhat longer period, there was evidence that N application had negative growth effects in later years (Tamm 1980). Only a small part of the added nitrogen could be accounted for in stand and soil, so losses with leaching and denitrification must have been considerable. After clear-felling, nitrification increased strongly on previously fertilized plots and a considerable leaching of nitrate occurred in a pot experiment (Tamm & Popovič 1974). However, as soon as vegetation recolonized the soil (and also the pots), nitrate concentrations and leaching returned to normal low values (Fig. 6). A certain soil acidification remained on the strongest fertilized plots.

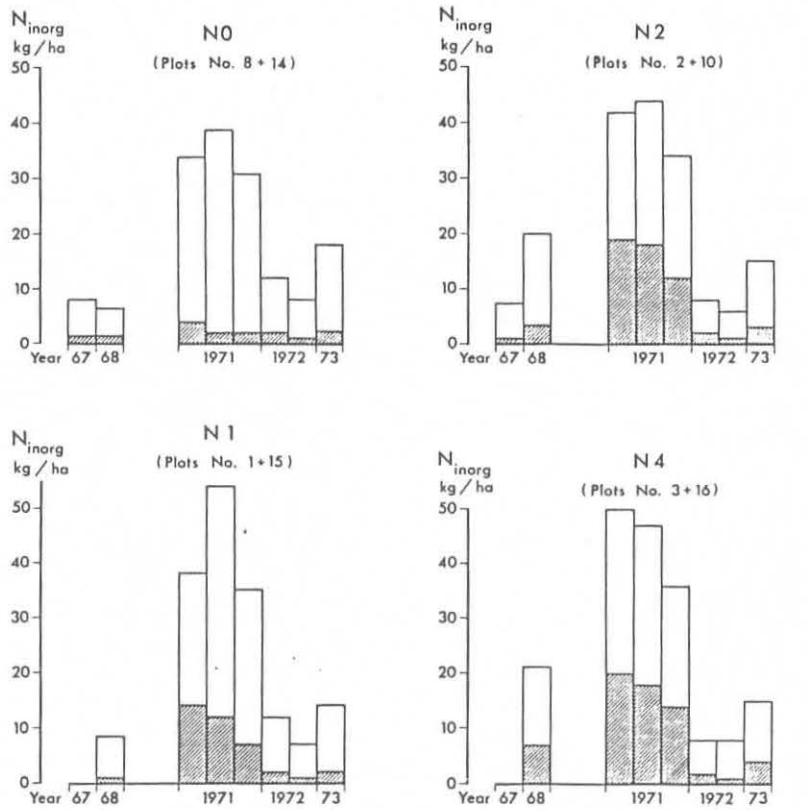

Fig. 6. Amounts of nitrate (hatched columns) and ammonia nitrogen (white) in the top soil (0-20 cm) of differently fertilized plots before and after clear-felling December 1970. From Tamm and Popovič 1974.

CONCLUSIONS

The problem of forecasting biological effects of slow environmental changes is a difficult one and has to be attacked by different approaches, as no single method alone can solve the problem. While comparative field studies, process studies in the laboratory, and mathematical modelling may all deal with a wide range of conditions, large-scale field experiments can only comprise a limited number of treatments and site conditions for obvious cost reasons. However, present experience indicates that well-planned field experiments may supply information on the effects of accumulated acid or nitrogen in forest ecosystems within a relatively short time (one to two decades), information hardly obtainable in other ways.

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